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STUDY & MODIFICATION OF

CONVECTIVE STORMS

Interim Report No. 2
Contract No. DA 36-03956-89066

Order No. 265-62, Project Code No. 8900
Dept. of the Army Project 3499-27-005-06
Second Interim Report Covering the Period
April 1, 1963 to June 30, 1963

U.S. Army Electronic Research & Development Laboratory
Fort Monmouth, New Jersey

MRI63 IR-87

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Study and Modification of Convective Storms

Interim Report No. 2

Contract No. DA-36-039 SC-89066, Modification No. 3

ARPA Order No. 265-62

Dept. of the Army Project No. 3A99-27-005-06

Project Code No. 8900

Second Interim Report, covering the period April 1, 1963 to June 30, 1963

Object of the Research: To obtain a quantitative understanding of the physical mechanisms involved in convective storms (nucleation, hydrometeor development, electrification, cloud and storm dynamics), both for natural storms and storms which have been artificially modified.

This report prepared by: Dr. P. M. MacCready, Jr.
Mr. T. J. Lockhart

PURPOSE

This basic research program is directed toward obtaining a quantitative and qualitative understanding of the physical mechanisms involved in natural and modified convective storms. The various phases of the convective phenomena are considered from a balanced, integrated viewpoint. The aim is to investigate and understand critical factors such as: nucleation, hydrometeor development, electrification, cloud dynamics, environmental effects, and the complex interrelations between all these separate items. The research technique is built around the concept of an outdoor cloud laboratory, treating the clouds and storms in the simplest possible real situations. Seeding is used as a diagnostic research tool to permit observations of direct and secondary effects on hydrometeor development, electrification, and cloud dynamics.

The program necessarily has entailed the development of some equipment and field study techniques. Success of the field program relies on an extensive coordinated effort using radar, other ground observations, and light aircraft systems. These tools must be coordinated so they can probe the dominant factors simultaneously. Certain critical subjects have received special emphasis up to the present time and the future course of the program will be to focus even more sharply on the specific areas which are now being shown to be critical.

The second year of this two-year program is divided into three phases: (1) the planning, preparation, and instrumentation technique development; (2) the field program itself; and (3) the data analysis. Phase (1) is completed and is reported on here. Phase (2) has just begun and cannot be included. Phase (3) has also begun to a small extent but will be the prime project objective only after sufficient field data has been collected.

ABSTRACT

This interim report describes the results of the preparation phase of the second year of the current program of basic research in cloud physics, cloud dynamics, and related cloud modification.

As a result of many internal planning meetings the scope of the research program has been specifically defined. The subjects, which are described in this report, are 1) General Cloud Microphysics and Dynamics Study, 2) Cloud Cell Dynamics and Edge Study, 3) Seeding, 4) Droplet Concentrations, 5) Mountain Wake Effects, 6) Thermal Roots Relative to Mountains, 7) Cloud Area Dynamic Effects, 8) Cloud and Precipitation Development Census, 9) Thunderstorm Created Cold Front, 10) Electrification, 11) Freezing Nuclei, and 12) Technique Development.

The instrumentation necessary to pursue these goals has been built, assembled, and installed at Flagstaff. Details of the major systems are described and include the Radar System with M-33 and MR-4 radars, the Aircraft System with an instrumented Piper Apache and Cessna 180, and the Photographic System with eight time lapse cameras and three radar cameras.

Facilities for operating the field project are described, and such general operational plans as are possible to formulate are included. In this area the emphasis on data handling and timely field analysis can be seen.

The presence of Dr. Schaefer, and his students, presents an opportunity to assist young science students in becoming familiar with field research and to contribute to the goals of the project. To this end a list of suggested research topics for student participation is included.

PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

There have been no publications as yet under this contract.

Study and Modification of Convective Storms, Report No. 2, Final Report covering the period April 1, 1962 - March 30, 1963 has been submitted, approved and distributed. A documentary film has been completed as an appendix to this report and a print of this film has been delivered.

No further lectures, reports, or conferences have been made or held during the period covered by this report.

DISCUSSION

A. Scope of the Research Project

General

The operational system has been designed so that the following subjects receive attention this summer. The list is long, but several of the items can receive some attention on a single flight. In every case the measurements are made to provide quantitative data pertaining to an existing physical model. Every item on the list should receive some attention, but the weather and operational circumstances will have a bearing on the emphasis of each.

General Cloud Microphysics and Dynamics Study (Todd, Woodward)

This is the main program for study and consists of many interrelated items. The primary research tool for it is the Apache aircraft, with the tracking and meteorological radars, time lapse cameras, and ground network also deeply involved. Most of the investigations are to be made for seeded as well as unseeded clouds.

One study is the analysis of spiral ascents in upcurrents up into cloud cores (previous or subsequent traverses provide environment data). Each analysis can show temperatures, upcurrent strength, droplet concentration and size evolution, amount of mixing, ice crystal concentrations and development, electrification (hydrometeor charges and potential gradient), buoyancy and hydrometeor growth - in effect, the dominant microphysics properties and some of the cloud dynamics properties.

Another operation involves systematic traverses through the clouds, at various levels or in a descending flight mode. This exposes more readily certain cloud dynamics features, especially the extent of unmixed cloud air, and details of cloud size and continuity. As with the spirals, it also shows microphysics items and buoyancy.

The studies are directed toward specific answers concerning:

- Droplet concentrations
- Ice crystal concentrations
- The extent of unmixed air (and the turbulence relating to this problem)
- The development of droplets and ice crystals, and the initiation of hydrometeors
- Electrification initiation
- Buoyancy vs cloud development

The studies are also related to many of the special topics to follow.

Cloud Cell Dynamics and Edge Study (Woodward)

Certain of the general operations will focus on individual cloud dynamics, with special attention to cloud cell edges and tops. The flight maneuvers will be modified accordingly, and the phototheodolite concentrated on the cloud section in question. Attempts will be made to use the M-33 tracking balloons and the aircraft so as to obtain Lagrangian motions within the clouds, especially in turbulent outflow regions near the top.

Seeding

Seeding will be performed by (a) AgI generators on the Cessna 180 operating either in the upcurrent under a particular cloud for high concentration studies or close to the ground far upwind to serve as a mobile ground generator for low concentration studies; (b) AgI roman candle type generators on the wing of the Apache for seeding AgI pellets systematically down from high altitudes; and (c) a 100-lb. motor-driven dry ice dispenser in the Apache for systematically releasing pre-ground pellets from aloft. Small and large scale seeding is to be performed as appropriate by each method, to permit as far as possible, evaluation of the effects of such seeding on the cloud droplet composition, hydrometeor development, and cloud dynamics (including buoyancy, growth, and decay). The cloud physics and cloud measurements discussed previously will thus involve unseeded and seeded clouds, so as to permit derivation of quantitative meteorological seeding effects. The quantitative details of the seeding will also be studied simultaneously to establish the concentrations of ice crystals at various elevations and temperatures resulting from each type of seeding. A primary aim of the program is to establish the existence of distinct seeding effects in as large clouds or cloud systems as possible.

Droplet Concentrations (Todd, Chien)

The relation between cloud droplet concentration in a cloud and upcurrent strength in the first few tens of meters in the cloud base will be established by systematic traverses and spirals. These studies will automatically be part of the routine cumulus studies, but will also be the aim of several special flights.

Mountain Wake Effects (T. B. Smith, Schaefer Students)

This will be checked regularly by the aircraft, especially with IR, turbulence, temperature, and rate of climb, and by low lift balloon trajectories. On at least one special day, which can be on a weekend, with all of Schaefer's students participating, more detailed studies should also be made including Apache measurements, surface winds, temperatures, tethered balloons, zero lift balloons, and smoke generators. The study requires a fairly strong wind situation.

Thermal Roots Relative to Mountain (T. B. Smith, Schaefer Students)

Some data will be obtained regularly by wind recorders on the mountain slope, for correlation to the time lapse camera and tracer balloon motion data. On at least one special day which can be on a weekend, detailed studies relying on all of Schaefer's students, time lapse Apache measurements, cameras, tethered and zero lift balloons, and smoke generators will be made. The study requires a weak gradient pattern.

Cloud Area Dynamic Effects (T. B. Smith, Schaefer Students)

Both mountain wake and slope studies have demonstrated the importance of the mesoscale patterns of cloud masses. Special attention should be paid to this problem by the convenient balloon tracing afforded by the M-33, for the areawide divergence - convergences may be detectable.

Cloud and Precipitation Development Census (Todd, T. B. Smith)

Time-lapse photographs and aircraft measurements provide daily summaries of cloud developments. From the available radar data similar information on precipitation cell development is provided, and all these are to be related to the ground synoptic environment.

Thunderstorm Created Cold Front (T. B. Smith)

On one occasion, with the Apache and at least a single ground site with wind and temperature data and a smoke generator (and preferably also tethered balloon or tower information) will attempt to check temperature and outflow characteristics of downdraft area from one storm which can enhance subsequent cloud dynamics. This may prove feasible late in the day of a mountain slope cumulus root study.

Electrification (Proudfit, MacCready)

A variety of studies are planned, the exact extent to vary with the available time and weather and the suitability of space charge measuring equipment. The studies will include:

(a) Measurements of hydrometeor charges in various stages of thunderstorm evolution, looking for systematic effects and especially checking the charging during melting both in and out of clouds.
(b) Gross electrification features, from airborne and ground potential gradient measurements and from qualitative lightning observations. Overall charge dipole verification.
(c) Space charge data, especially around and in small clouds and at the edges and upper portions of electrified clouds. Of great importance is the measurement of the relative contribution of hydrometeors and droplets to the net positive charge at the cloud top.
(d) Several soundings with the conductivity meter, and its continuous use on the ground.
(e) An investigation on the ground of physical hail structure, with special emphasis on bubble release vs electrification. Also airborne laboratory investigation of charging during melting.

Freezing Nuclei (Woodley)

The filter technique of Bigg and Lodge will receive further study and be employed for systematic natural freezing nuclei measurements. Airborne measurements are considered especially desirable.

Techniques

This field program is aimed basically at utilizing techniques developed previously but the development or acquisition of new equipment makes some technique study warranted. Subjects include:

(a) Use of smoke generators for wake and thermal root studies.

(b) Use of roman candle type silver iodide generators, and steady pellet release of dry ice material.

(c) Comparison of the 8-12μ band infrared device with ground temperature and surface air temperature.

(d) Evaluation of the improved continuous droplet sampler.

(e) Utilization of new or improved atmospheric electricity instrumentation, especially hydrometeor charge, potential gradient, space charge, and airborne laboratory melting-charging tunnel.

(f) Optimum use of the M-33, for aircraft and balloon tracking, and, with the aircraft true airspeed unit, the measurement of horizontal winds; and possibly D values for the aircraft overhead; perhaps turbulence data from zero lift balloons for comparison with the aircraft turbulence. The balloon technique can include fuzed releases of zero lift balloons from ascending balloons.

(g) Hydrometeor sizing device on the aircraft.

(h) Freezing nuclei filter technique.

B. Instrumentation

Radar System

Two radar trailers containing three radar sets will be used to track aircraft and balloons and to describe precipitation cells in three dimensions. The M-33 system employees two radar sets and will be used primarily for tracking. The MR-4 system using its PPI-RHI capability will measure precipitation cell development.

The M-33 tracking radar employs a 250 KW transmitter in the 3 CM band and a "pencil beam" antenna with a beam width of about one degree. It has an X - Y plotter giving the plan position of the tracked target. The plotter was modified to provide two horizontal distance scales; 0-40, 000 yards (0-20 nautical miles or 1:100, 000 scale) and 0-80, 000 yards (0-40 nautical miles or 1:200, 000 scale). The range-altitude plotter has been modified to be a time-altitude plotter with a paper drive speed of 1 mm per second and a variable altitude range in excess of 30, 000 feet above the radar. Both the X - Y plot and the T - A plot have time marks at 30 seconds, 1 minute or 2 minutes selectable by the operator. A high powered optical system is built into the antenna for visual tracking when desired. Dial readouts give continuously the target range in yards and azimuth and elevation angles in mils.

The M-33 acquisition radar employs a 1, 000 KW transmitter in the 10 CM band and has a "banana peel" antenna which is very broad in elevation but narrow in azimuth angle. The PPI presentation gives slant range in yards and azimuth angle in mils over a range of 120, 000 yards (60 nautical miles) with precision ranging capability to 96, 000 yards (48 nautical miles). One ten inch PPI scope was added to the two original scopes for the purpose of photographing the data. A time-lapse radar camera, with a synchronous digital clock with special sweep second hand in the field of view, takes one picture per antenna rotation. The target being tracked by the tracking radar is indicated electronically on the acquisition scope by superimposing a cross on the proper target on the acquisition scope. This cross will appear in the radar photographs.

The M-33 system is powered by a 400-cycle three-phase diesel motor-generator mounted on a trailer.

The MR-4 weather radar is basically the same as was used on earlier field programs. It has an 80 KW transmitter in the 3 CM band and a "pencil beam" antenna with a beam width of two degrees. The antenna drive has been modified to operate either in PPI or RHI mode or to automatically program the antenna mode for both PPI and RHI information with receiver gain stepping and pulse integrating capability. The radar has ranges of 0 - 35 nautical miles or 0 - 120

nautical miles. Three seven inch scopes and one ten inch scope display the radar echoes simultaneously with two of the smaller scopes equipped with radar cameras. These cameras take one picture per PPI rotation or per RHI sweep and include in the field of view time and other important bits of data. The MR-4 is powered by commercial 115 volt 60 cycle single phase power.

An additional M-33 radar, tracking only, will be in operation as part of the USAERDL equipment and will be used primarily to track USAERDL aircraft.

Aircraft Systems

The primary instrumented aircraft is a supercharged twin-engine Piper Apache which has been equipped with special electrical power capability. One engine operates a 100-amp 24-volt alternator and the other a 50-amp 12-volt generator. Fifty amps of the 24-volt power is used to provide 1,000 watts of 110 volt 50 cycle power through a voltage stabilized inverter. The principle instrument system employs a six-channel Brush electric writing oscillograph, a cycling and "sparking" unit to allow for time-sharing on each channel and a non-continuous writing mode, and the various amplifiers, measuring circuits, and sensors described below.

1. Temperature (Channel 1) is measured with a fast response thermistor bead (Veco #41A5, 0.08 seconds time constant) mounted in a vortex housing for automatic airspeed compensation. The measurement circuit has twelve ranges of eight degrees centigrade each covering a range of -34° to +40° so that there is a 2° overlap on each end of each scale to decrease scale switching. The temperature module contains circuitry for automatically finding the correct scale and switching to new scales when necessary. A standard binary code identifies the scale through the use of five stationary event pens located between channel 1 and channel 2.

2. Altitude (Channel 1) is sensed by a standard sensitive aneroid altimeter which has been exhaustively calibrated and which has a vibrator attached to it to decrease the effect of frictional drag in the linkages. To record the altitude a "light follower" is mounted to the face of the altimeter and is adjusted to home on the hand,which makes one revolution per thousand feet,thereby slaving the wiper of a potentiometer to the altimeter hand. The recorder plots the hand position resulting in a "saw tooth" trace for ascending or descending flights with 1,000 feet per cycle as the scale. Identification of the actual height is simple, given the take-off elevation,so special "scale identification" is unnecessary.

3. Turbulence (Channel 2) is measured using a propeller driving a chopper which interupts a light path to a photo cell twenty times per revolution. The propeller has a diameter of four inches and a blade angle of ten degrees. The Universal Turbulence Meter senses change in horizontal wind speed converting this to a single value representation of the turbulence spectrum. Changes in

aircraft speed are electronically eliminated from the measurement. This unit has two scales, one a factor of four attenuation of the other, and the scale in use is indicated with two of the five stationary event pens located between channel 2 and channel 3.

4. True Air Speed (Channel 2) is measured by simply tapping the turbulence unit at a point where the signal is proportional to the rotational speed of the propeller sensor. An expanded scale representation is used where the range of 27.5 to 87.5 meters per second occupies full scale on the recorder.

5. Rate of Climb (Channel 2) is measured with a fast response electric Crossfell variometer as well as measured on a coarser scale with the altimeter. The electric variometer works on the principle of pressure change with a flow sensor measuring the flow in or out of a thermally insulated one liter air reservoir. The full scale range on the recorder is -25 to +15 meters per second.

6. Mixing Ratio (Channel 3) is measured with an MRI Model 901 Mixing Ratio Meter. The sensor is mounted in a small diffusion chamber on the aircraft with the intake hole protected from any inflow of particles larger than a few microns and the sensor oriented to minimize inflow of smaller drops that might enter the diffuser. The sensor coated with phosphorus pentoxide electrolizes all water vapor which enters the sensor with the current flow in the sensor directly proportional to the mass of the water vapor. The flow through the sensor, which is on the order of 5 cc per minute, is servo controlled to maintain a constant mass flow so that the current measured can be directly related to grams per kilogram mixing ratio. Five overlapping ranges are used with automatic range switching selecting the proper range. The ranges are 32 - 12, 16 - 6, 8 - 3, 4 - 1.5, 2 - 0 utilizing five eighths of full scale on the recorder. The range in use is identified with a binary code using three of the five stationary event pens located between channel 3 and channel 4.

7. Liquid Water Content (Channel 3) is measured with a Johnson-Williams instrument which uses a hot collecting wire in a cylindrical housing containing a de-icing heater and a non-collecting reference wire. Liquid drops smaller than 50 microns are completely evaporated on the collecting wire and the cooling of the wire is measured and is linearly proportional to liquid water content. Only one range is used for recording and that is 0 - 8 grams per cubic meter full scale on the recorder.

8. Infrared Temperature (Channel 3) is measured with a Barnes Model IT-1, 14-312 Optitherm unit. The sensor has a 2° beam width and is mounted pointing down through a hole in the bottom of the aircraft. The radiation temperature in the 8 to 13 micron band which it measures is recorded over the 20 to 100 degree F. range of the instrument.

9. Heading (Channel 4) of the aircraft is measured by using a gyro compass referenced to a magnetic compass which has a remote read-out meter in the

instrument system. A "light follower" identical to the one described in paragraph 2. above has an output to the recorder such that 0 - 360° is full scale on the recorder channel.

10. Drop Mass (Channel 4) will be measured in the range of 1 - 10 mm diameter drops on an experimental basis using a new instrument with a pulse output for each drop through the sensor where the pulse height is proportional to the mass of water in the drop. Recording this variable will be attempted on the Brush recorder at high paper speeds but it may be only possible to get accurate pulse heights with an oscilloscope.

11. Hydrometeor Charge (Channel 5) is measured with an open ended Faraday cage mounted on the aircraft in such a way as to allow hydrometeors to pass through unaffected by the sensor. The charge is measured over a range of 0 - 2,000 picocoulombs which is displayed and recorded on a nonlinear scale to avoid range switching and without experiencing a significant loss of resolution. This variable also requires a fast paper speed and will be measured also with an oscilloscope.

12. Simulated Hydrometeor Charge (Channel 5) is measured by using a rod six inches long and three millimeters in diameter with a rounded leading edge so that from the collection standpoint it is like a 3 mm sphere. This probe is shielded from potential gradient effects and the accumulated charge is measured by an electrometer.

13. Space Charge (Channel 5) is measured with a larger open ended Faraday cage than the hydrometeor charge sensor described above and with a more sensitive electrometer with a time constant of about three seconds.

14. Potential Gradient (channel 6) is measured using two probes with separate electrometers, one located above and one below the fuselage. The probe heights can be balanced electrically in flight and the vertical gradient determined by subtracting the outputs of the two electrometers. The output can be recorded on either of two ranges; a linear sensitive range from 0 to 300 volts or a nonlinear range of 0 to 15,000 volts. The range is automatically identified by two of the five stationary event pens between channel 2 and channel 3.

15. Aircraft Charge (Channel 6) is measured with the same sensors and and electrometers as the Potential Gradient unit described above. The two outputs are added for aircraft charge with the same two-range capability as the P.G. unit. The P.G. range switch operates the aircraft charge range and additional range identification is redundant.

16. Program Control A cycling switch capable of sampling an output at least twice a second is used for providing time sharing on each of the six channels and a synchronized marking circuit plots one point per sample. Each channel has a program switch allowing the operator to record continuously any one of

the variables designated to the channel or to record all variables in the cycling mode. When cycling is employed a full scale calibration point is automatically included in each cycle except for once a minute when a zero point is substituted for about seven seconds.

17. Time is measured with a mechanical escapement type one minute timer which is manually started on signal from a control time source set to WWV. Each minute is marked on each channel when cycling by the switching of the full scale calibration signal to the zero signal. When not cycling, or at the discretion of the operator, the time can be marked by a pulse on the left margin event marker.

18. Voice Recording is available by the use of a Stenorette recorder coupled to the microphones in the aircraft radio system and controlled by a switch panel which allows intercom talk, radio transmission, or dictated notes to be recorded with the proper switch settings. When the recorder is operated with the microphone button the left margin event marker moves to its on position and remains there until the recorder is stopped. The time pulse mentioned in 17. above, operates from either the on or the off position of the event marker with the pulse base remaining with the pen position and the pulse direction reversing when the position changes.

19. Event Marks are put onto the right margin event marker in two ways. An IN-OUT of cloud button controls the position of the marker pen so that the cloud size is recorded for significant penetrations. An EVENT button puts a pulse on the trace on the right margin in exactly the same way as the time pulse is recorded on the left margin.

20. Special Recorders may be used for some flights, principally for the atmospheric electricity experiments, where faster response or faster chart paper drive is desired for some but not all variables. A provision has been made for the addition of a two-channel Brush recorder for these flights. Where fast response is critical a Techtronix oscilloscope can be used to monitor the recorded signals to accurately measure pulse heights and check to see that the recorder is properly following instrument output.

21. Droplet Sampler data is taken continuously through clouds with an instrument which collects small water or ice particles by impaction on clear 16mm film leader coated with a formvar-chloroform solution. The solvent is quickly evaporated leaving a durable translucent replica of the droplet or ice crystal as it appears after impaction. A specially modified projector supplies uncoated film to the sampling head and takes up dried, exposed film after running it through an optical monitoring system. A "frame" counter logs the use of film which is exposed at about 0.3 feet per second and three of the stationary event pens between channel 4 and channel 5 on the recorder mark the exposure of each 10, 100, and 1,000 frames for time correlation. One frame is 0.025 foot long and since the collector has no shuttering action the frame is used only as a convenient unit of length.

22. Time-Lapse Camera pictures are taken at the operator's discretion with a camera pointing through the aircraft windshield. The rate of exposure is continuously adjustable from 1 second to 120 seconds per frame and will normally be operated at about 10 seconds per frame for monitoring and at about 1 second per frame during tests. Exposed frames are marked on the recorder by having three of the stationary event pens between channel 5 and channel 6 indicate each 1, 10, and 100 frames for time correlation.

23. Dry Ice seeding can be done with the Apache by using a 100 pound capacity continuous dispenser at one of several metered rates.

24. Special Equipment will be used for measuring air conductivity and graupel size and provisions will be made for collecting water samples for contamination analysis. Some in-flight tests will be made of the electrical effects of melting graupel in the miniature ice melting wind tunnel.

A Cessna 180 will be used primarily as a seeding aircraft and for this mission it has been equipped with two airborne silver iodide generators of the design used by the USFS Forest Fire Laboratory at Missoula, Montana. Special seeding using pyrotechnic equipment furnished by the Naval Ordnance Test Station, China Lake, California will be tried as a massive seeding experiment. Temperature and humidity measurements may be made with the 180 should the requirement arise. The aircraft is also equipped as an airborne smoke generator and will be used in this mode for flow studies.

It is planned to have two high altitude photographic flights made by a USAF U-2 from Edwards Air Force Base on days forecast to be optimum for this type of data.

USAERDL will operate an R4D which is instrumented for IR temperature measurements and for air temperature with an indicating MRI vortex thermistor thermometer. This aircraft will also be used to dispense chaff.

USAERDL will also operate an AD-5 for condensation nuclei seeding.

Photographic Systems

The primary photographic goal is to describe as accurately as possible the exterior of clouds in the vicinity of the San Francisco Peaks. All of the cameras for this purpose are 16 mm cameras operated in a time-lapse mode. The two mose useful cameras are the Bell & Howell cameras operated in the MR-4 trailer, eleven nautical miles south of Mount Agassiz. At this distance most of the cumulus activity of interest can be photographed in detail with 10 mm wide angle lenses. One camera is always pointed due north at the peaks and the other is pointed either to the left or to the right depending on the area of interest. The cameras have slightly overlapping fields of view, are triggered from a common timer at selectable rates from 1 second to 140 seconds per frame,

and have the same electric digital clock in the field of view. These cameras are operated by a photo electric switch so that the full day can be photographed without early morning or late evening attenuation. Normally the unattended rate will be one frame per minute with the rate increased to about seven seconds per frame during the active part of the day.

To augment the "control" cameras just described, are three automatic remote cameras. These are all Keystone cameras with MRI automatic winding and time-lapse attachments and 16 mm wide angle lenses. The camera is mounted inside a white box for radiation protection and is operated by a one minute timer operating through a photoelectric switch for night time shut off. A clock is in the field of view as is a horizon marker to ease subsequent analysis. The cameras all face the peaks; one is 34 miles ESE of the peaks at Meteor Crater; one is 28 miles NNE of the peaks at Gray Mountain; and one is 28 miles NW of the peaks at Grand Canyon Airport.

A fourth remote camera is operated as one of a stereo pair in conjunction with the north pointing "control" camera. It is similar to the three described above, but a 10 mm lens is used because of the closer location and the camera has the capability of operating with an adjustable timer or by radio control slaved to the control timer.

To complete the cloud surveillance network a "whole sky" camera is located at Fort Valley, 5 miles SSW of the peaks. This Bell and Howell "electric eye" camera photographs at one frame per minute the image seen in a 16 inch parabolic reflector. Also in the field of view are a clock, a thermometer, a wind vane, and a wind speed counter.

Other 16 mm camera recorders mentioned earlier are the three radar cameras and the one aircraft camera. A Bolex is used at the standard motion picture speeds to record the activities of the project and to photograph special events.

The photographic system includes other cameras of different sizes and uses. A phototheodolite has been modified for time-lapse use for the study of cloud edge and top motions. It also has a clock in the data recording area as well as azimuth and elevation angle. A Polaroid camera is used to help describe the cloud population each day as well as to document special events for future identification and analysis. A 3 1/4 x 4 1/4 Speed Graphic is also used for special cloud photography and for documenting instrumentation on the ground and on aircraft. Most of the photographs described in this paragraph will be taken from the airport headquarters.

Miscellaneous Instruments

A variety of meteorological instruments are available for routine or special studies where extra data is needed. Some of these are described as follows:

A ground station will be operated near the Research Center of the Museum of Northern Arizona to measure the surface micrometeorology of a uniform field. Data from the IR thermometer in the aircraft flying over this station will be correlated with the "ground temperature" as measured by the ground station, to gain better understanding of the IR data. A ten-foot mast is instrumented with a VectorVane on top, a shielded thermistor on top, and at one foot above the ground, and a thermistor just below the surface of the soil. Two two-channel Esterline Angus recorders with associated MRI measuring circuits are used to record wind speed, wind direction (horizontal), and turbulence level as sensed by the VectorVane reaction to vertical wind flow. Temperature is measured on a time sharing basis with each of the three thermistors recording consecutively for about five minutes each.

Pressure effects of cumulus will be recorded at the Research Center and other locations with a special microbarovariograph which has a full scale sensitivity of about ± 0.5 mb with a five gallon air reservoir. Three conventional micro-barographs will be provided by USAERDL to augment the measurement of pressure effects.

Ground atmospheric electricity measurements will be made at a number of points. A potential gradient recorder will be operated with the whole sky camera at Fort Valley. Three additional potential gradient recorders will be used for special projects principally at the Research Center and at the airport. An air conductivity meter will be operated at the airport and at the Research Center. Some aircraft instruments will be used on the ground when not required for flight recording; principally the hydrometeor charge unit and the drop mass unit are proposed for this double duty.

For special measurements of slope heating and mountain wake effects, ten kits were assembled to be used by observers (primarily students) as an aid to describing surface flow and temperature fields. The kits contain the following instruments: a sensitive wind vane capable of responding to eddy sizes of the order of one foot; a transparent compass rose through which the wind direction can be read to five degree accuracy; a Dwyer pellet anemometer, a thermistor thermometer with a range of 0-40°C; a small sling psychrometer; a compass; and a Devil Level for leveling the vane mast and also capable of measuring elevation angles. During some days teathered 100 gram balloons will be used to indicate the flow at 50-200 feet above the ground. For these measurements the kit provides means for measuring the azimuth and elevation angles of the balloon to the accuracy needed.

An excellent tool for studying flow is the smoke generator. Two of these semi-portable, high output units will be used along with the smoke generator on the Cessna 180 for special projects. Spare time-lapse cameras will be available to record the smoke plumes to augment visual observations and notes.

Four simple automatic wind recorders (three from USAERDL and one from MRI) will be placed around the peaks to measure mean flow as well as to detect the effect of the mountain mass on the mean flow. These completely mechanical sensor-recorders are essentially maintenance free and therefore provide very useful data at minimal cost.

Various other instruments and items of test equipment will be used but need not be detailed here. All equipment being used by USAERDL and other groups are not listed in any detail as that information is not available at this time.

C. Facilities

The operational headquarters is located at Flagstaff Municipal Airport where two general areas are used for the many functions required by the project. A hangar with approximately 4500 square feet including two small rooms, is used for aircraft servicing, instrument assembly and staging, storage, mixing chemicals, crushing dry ice, and other miscellaneous tasks. The two rooms are used as electronics shop, part time dark room, stock room, balloon shed, and laboratory.

The main operational facility is a trailer complex adjacent to the beacon tower in a triangular lot at the airport entrance. An office trailer with 500 square feet in three rooms, serves as administrative headquarters, data control center and field analysis area. Pre-flight and post-flight briefings and operational planning meetings are held here in the data control office. Project monitoring takes place in the data control office where there is a good view of the peaks and where intercoms and radios keep the monitor abreast of all activities in the air and in the radar trailers. Time correlation emanates from this point where a WWV receiver is located. The analysis area also has a good view of the peaks and is equipped with the linear pantograph and its associated data table, the droplet sampler analysis projection booth, and a Verifax copier for data reproduction. The administrative office has conventional equipment and needs no further description.

The MR-4 trailer provides flight operation control space as well as housing the radar set. From a position commanding full view of the peaks, the controller has at his immediate disposal repeater scopes from the MR-4 and M-33 radars to show cloud echoes and aircraft positions. With this information, plus additional data available from the M-33 by intercom, the controls can direct the aircraft by radio toward accomplishment of the flight objectives. The controller can also direct ground vehicles by radio if necessary.

The M-33 trailer parked adjacent to the MR-4 trailer normally provides only data to the project, but it has the capability of directing aircraft movements by radio should the controller ask for this service.

A USAERDL electrification and headquarters trailer will be located in the trailer complex for maximum coordination. It will be tied into the intercom network to facilitate communication to other operating centers. Radio communications to all USAERDL aircraft and to MRI aircraft when necessary, will originate from this trailer.

An additional M-33 radar provided by USAERDL will be located either at the trailer complex at the airport or at the Navajo Army Depot.

Facilities are provided to USAERDL at the Navajo Army Depot for their pibal equipment and crew and perhaps for other purposes which cannot be detailed at this time.

D. Operational Plan

Because of weather variability it is impossible to specify test plans chronologically. Some general scheduling is possible and several specific procedures can be defined and applied to many test goals. The general emphasis for the field program is listed as follows:

July 8 - 13	Emphasize radar tracking of aircraft and balloons. Take routine aircraft measurements. Continue calibrations.
July 15 - 20	Special aircraft studies. Major seeding efforts. One wake or slope event.
July 22 - 27	Same as previous week but with greater emphasis on electrification studies.
July 29 - Aug. 3	Same as previous week but including quantitative in-cloud generator studies.
Aug. 5 -	As required.

A routine for all operational days can be described in some detail as follows:

0700	Prepare for planning briefing - Study Winslow sounding, NAD pibal and current weather maps.
0730	Briefing - Technical meeting to make any last minute changes in the day's objective and to plan the day's operation in detail, consistant with current weather conditions.
0730	M-33 on air
0800	Launch radar balloon from NAD or airport for maximum mountain effect.
0800	Check and set all clocks to WAV
0800	Begin Apache pre-flight instrument checks
0830	MR-4 on the air
0845	Apache ready for take-off
0900	Service IR station at Research Center
1530	Briefing - Technical meeting to survey summary of day's operations. Evaluate degree to which day's objectives were satisfied. Examine pertinent data. Plan objectives for the next day consistant with current forecast. Note - the time for the afternoon meeting must be flexible to assure maximum attendance by principal scientists.

Some standardization of Apache flight operations is desirable and to this end the following procedures and schedules will be used where possible.

1. Standard Flight Schedule

   A. Take-off

   B. Traverses at 1,000 feet above terrain over 2 predetermined areas (Lake Mary and Research Center) emphasizing IR, preferably two traverses over each area - one crosswind and the other upwind-downwind to ground level flow.

   C. Circle around peaks at same altitude above terrain ($\sim$9,000 feet) including Sunset Crater, Crater Lake, etc. to study updrafts, IR, etc. Then ascent to peak top altitude and make pass over Agassiz to bowl. Over bowl, make turn to area at base of slope and make downwind traverse at peak top height to at least 10 miles beyond peaks (wake study).

   D. Cumulus study operations.

   E. Descent from cloud base surveying storm areas, etc.

   F. Repeat of Step B.

   G. Landing.

   Note: All flights, regardless of flight objective, should attempt to do Steps B and F. Step B should be done whenever time is available during a flight.

2. Standard Flight Patterns

   A. Spiral up through cloud - if possible, through base and top of cumulus, at a regular predetermined rate of ascent. Obtain environmental measurements on following descent - traversing cloud. Make 2 or 3 traverses if possible.

   B. Vertical slice pattern through the cloud making crosswind or upwind and downwind traverses (4 to 5 in the cloud) starting above the cloud tower and working down through the cloud at regular intervals to below the cloud base (or starting below the cloud base and working up through the cloud at regular intervals to above the tower). One traverse should be through the top 500 feet of the cloud, one through the cloud base and a couple through the updraft area under the cloud base, before or after the cloud traverses, when appropriate.

      Option #1 - 180°. Make a 180° turn (standard to the left) at end of each traverse, re-entering cloud parallel to and about 2,000 feet to one side of the course of the previous traverse (best for constant level).

Option #2 - 90° and 270°. Make a 90° followed by a 270° turn at end of traverse to re-enter cloud on same course as previous traverse (Best for ascent or descent).

C. Cloverleaf pattern through the cumulus making crosswind and upwind and downwind traverses (in the cloud perpendicular to each other), working the cloud as described under pattern B.

Note: Patterns B & C may be performed at constant altitude.

D. Cloud traverse specifications

1. Zero rate of climb (in still air) before entry. This is predetermined from previous flights.
2. Constant power setting.
3. Maintain constant heading and attitude throughout traverse.
4. Indicated airspeed 90 mph or 100 mph, to be specified after flight tests.

Note: For an ascending or descending traverse, a set rate of climb (constant power setting) should be predetermined before cloud entry.

3. Flight Objectives

A. Small scale study of cumulus towers - pass over tower, then series of traverses (about 3 upwind and downwind) through the growing tower, perhaps at the same altitude - including phototheodolite perpendicular to wind flow, active tower and at least 2 different cases (one where shear is negligible).

B. Condensation nuclei activation - at every opportunity make traverses through the cumulus, 500 feet above cloud base (area of no dilution) - emphasize droplet sampler and rate of climb.

C. Rate of change of cumulus structure - series of traverses at same altitude through same cloud using cloverleaf or vertical slice pattern.

D. Storm downdraft study - obtain shape and vertical motion structure of downdraft area ahead of large scale storm by making appropriate traverses.

E. Clear air study - series of traverses over and around the peaks at altitudes to about 20,000 feet to determine the clear air environment (pre-cloud).

F. Student slope project (Saturday) - varied traverses of SE slope of Peaks as directed, including IR, R/C, radar track.

G. Wake study (non-cloudy day) - series of parallel traverses, perhaps 4, upwind and downwind over peaks at directed altitudes, including potential temperature, R/C and IR.

E. Student Program Suggestions

General

Several of the projects listed below can be handled more properly by two students, more may be accomplished, and each student may get a deeper insight into the problems.

It would seem that there should be a formal mechanism each week (seminar) for the students themselves to describe to the remainder of their group (a) what they have done and why, and (b) where they are going next. Once or twice during the summer this should also be done for the benefit of the rest of the Flagstaff seminar.

Mountain wake studies and mountain slope studies are primarily attacked as group efforts because of the need for large area coverage. A limited amount of work can be done individually or by two students, however, prior to the group efforts.

Permanent wind station locations can be set up to concentrate on slope effects (SE slope - Doyle Saddle road) or wake effects (northeast of mountains if wind from SW). It is probably not wise to try to cover several areas with a loose network. It seems better to set up a more concentrated network at one location, then move everything to a new location after several weeks.

For the slope studies we would suggest three stations about 2 - 3 miles apart in a triangular network with good south to southeast exposure. These could be centered along the Doyle Saddle road but cover a portion of the slope east and west of the road.

For the wake studies, we got very ambiguous data from Cinder Lake last summer and were not able to understand it very well. It should be a good station location but perhaps it was too close to the edge of the wake. Last summer we got a lot of wind measurements along Hiway 89 but not much east of there. It would be profitable to get a location east of Hiway 89, perhaps on the interior road from Sunset to Wupatki. A location near the turnoff from Hiway 89 to Deadman and Saddle Mountain together with Cinder Lake would make a nice network.

Infrared Studies

1. Relate ground IR measured from aircraft with measured soil temperature at Research Center station.

2. Relate measured soil temperature and air temperatures at Research Center for various wind speeds, turbulence, time of day.

3. Measure area variations in soil temperature around Research Center site (group effort of several students).

4. Measure depth variations in soil temperature as function of time of day.

5. Compare heating characteristics (function of time of day) of dry and wet soils - same location - different days.

6. Measure water temperature of Lake Mary (middle of lake) at same time as fly-over with aircraft to calibrate IR unit in plane. Measure at several heights in top 6 inches of lake.

7. Record IR measurements at several specific locations as measured by aircraft. Try to explain differences from day to day as function of wind, cloudiness, time of day, etc.

Slope Studies

1. Group effort with approximately nine tethered balloons in 3 x 3 grid along SE slope. Simultaneous measurements with aircraft of updraft, IR. Must be on quiet day with light pressure gradient so that heating predominates. Main parameter to measure is elevation and azimuth of balloon and compare to other locations in grid.

2. Release balloons from Research Center under light winds with slow rise-track with M-33.

3. Analyze data from wind instruments on slope for presence and duration of upslope flows.

4. Plot any IR temperatures of slope locations from aircraft to find area-heating characteristics (warm and cool).

5. Find air heating characteristics on slope. Variations in air temperature in meadow compared to under trees; over grassy vs. dirt areas, in cloudy shade and sun (time to heat after cloud has passed) - all measured at several elevations in lowest 6 feet.

Wake Studies

1. Group effort with multiple wind and temperature observing stations - records every 15 minutes including wind, air temperature, and top soil temperature (may be altimeter measurements also). Simultaneous aircraft measurements of IR, temperatures, and turbulence. Aircraft flights will be upwind and downwind over the Peaks, (a) one flight directly over the Peaks, (b) one flight on a parallel track about 5 miles north and (c) one flight on a parallel track about 5 miles south. Flight altitude 12, 000 feet. Repeat pattern of three flights at about 16, 000 feet, maybe higher also.

2. Analyze wind station network for presence of wake. Look for cloud indications of wake each day (first cumulus in lee of mountain and often shredded by turbulence).

3. Release balloons from variety of positions around mountain (upwind, downwind, sides) whenever M-33 available. Relate to flow around mountain.

Freezing Nuclei Studies

1. Work with Bill Woodley in further development of filter sampling technique.

2. Try to get sample of ice nuclei on filter in 180 aircraft flight each morning. Find distribution of nuclei with height.

3. Make several consecutive filter sample collections and develop in cold box at different temperatures.

4. Limited routine ice nuclei background counts (once per day) and relate to wind flow direction.

Condensation Nuclei

1. Make condensation nuclei readings at Research Center and relate to wind direction, speed, turbulence. Make readings before and after downdraft air arrives. Also before and after general shower.

2. Try to relate condensation nuclei data to number of drops formed at cloud base and recorded by aircraft drop sampler.

Microbarovariograph

1. Calibrate by frequent altimeter readings written on chart.

2. Relate variations to heating, turbulence, wind flow.

3. See next section.

Downdrafts

1. Try to study structure of cool downdraft air passing over Research Center. Measure temperature changes, wind velocity. Release balloons at intervals of 10 - 15 minutes with known lift and record time to marked wind shear (top of downdraft air). Record pressure effect on microbarovariograph with frequent altimeter readings on chart.

2. Record apparent location of parent storm. Try to observe effects of downdraft air on generation of new cloud areas. How long does downdraft air stay in Research Center location?

3. If additional microbarographs available, use on southern slope (Ft. Valley, Schultz Pass, Hiway 89 south to airport) unless needed for mountain wake study. Find time of travel of one downdraft front from one station to another.

Reduction of Aircraft Cloud Data

1. The analysis of cloud structure as from aircraft penetrations.

2. The analysis of sub-cloud structure as measured from aircraft flights.

3. Operation of the linear pantograph.

4. Analysis of drop spectrum records from the aircraft.

Electricity Studies

1. Hydrometeor electrification as measured on the ground with drop electrification and drop size instruments from the aircraft.

2. Lightning studies as relating to the general cloud situation and the characteristics of melting hail and its solid structure.

3. Hydrometeor size spectrum from "raindrop spectrometer".

Note: The exact topic selection will be made at Flagstaff and it is understood that not all of the above items can be covered.

CONCLUSIONS

As no field testing has been done as yet there are no conclusions to report. It can be stated that the preparation stage has been completed to a satisfactory degree considering the complexity of the new instrument systems and the lead time available prior to the beginning of the field program.

PROGRAM FOR THE NEXT INTERVAL

The most productive part of the research program lies in the next three quarters. The field program now in progress and scheduled into early August will produce the data upon which the advances made during this second year will be based. As pointed out earlier there will be considerable analysis effort expended in the field coincident with the gathering of data. This should yield partially formed conclusions on at least some of the project goals by the end of the field program. In addition, it will tend to insure well annotated data and operation summaries to greatly facilitate analysis after returning from the field. With this start it is expected that concentrated analysis effort will yield results with a maximum of efficiency in a minimum of time.

PERSONNEL

The field program requires the maximum flexibility in personnel utilization yet specific responsibilities must be assigned. The following lists will specify these duties.

Operational Responsibilities

	In Charge	Assisted By
Project Director	MacCready	(Smith, T., Todd)
Data Control	Beesmer, K.	(Smith, D., Woodley)
Calibrations	Woodward	(Proudfit, Beesmer)
Radar Systems	Clark	(Pate, Jones)
Aircraft Systems	Gretta	(Proudfit, Day)
Photographic System	Schley	(Jones, Woodley)
Aircraft Observations	Woodward	(MacCready, Proudfit)
Aircraft Coordination	Day	(MacCready)
Special Instrumentation	Proudfit	(MacCready, Johnson)
Droplet Collector	Williamson	(Hindman, Chien)
Communications	Jones	(Clark)
Administration	MacCready	(Lockhart, Beesmer, K.)

Routine Aircraft Operation Duty Assignments

Operations Coordinator	Todd
Operations Monitor	Beesmer, K.
Pilot (Apache)	Day
Pilot (Cessna 180)	Gretta
Observer (Apache)	Woodward
M-33 Radar Operator	Clark, F.
MR4 Radar Operator	Todd
M-33 Plot Operator	Smith, D.
Airport Camera Service	Woodley

Field Function Summary, by Individuals (* denotes part time in the field)

*Adams	General Helper
Beesmer, K.	Data control, chronicler, calibration, time, Photo documentation
Chien	Droplet film analysis
Clark, F.	Radar maintenance and operations, communications
*Davis	M-33 tracking
Day, R.	Pilot, flight coordination, aircraft supplies
Gretta	Aircraft mechanics and instrument systems, pilot, AgI generator
Driscoll	Secretary, records
Hindman	Droplet collector, freezing nuclei
*Johnson	Electronics
Jones	Communications, radar, cameras
*Lockhart	Administration, instruments
MacCready	Project Director, instruments, observer, pilot, inter-group coordinator

Proudfit	Aircraft instruments, observer, calibration
Schley	Cameras, general assistance
Smith, D.	M-33 plot, data, pantagraph
*Smith, T.	Special projects, research advisor
Todd	Operations, analysis, MR4 operations
*Williamson	Droplet Collector
Woodley	Data assistant, airport cameras, freezing nuclei pilot.
Woodward	Observer, calibration, analysis

The following list includes some of the people who will be visiting or working on cooperative efforts.

From the U. S. Army Electronic Research & Development Laboratory, Ft. Monmouth, New Jersey:

Weickmann	Project Director
Kasemir	Physicist
Kelly	Engineer
Waterman	Flight Coordinator
Paulson	Pilot
Emerson	Pilot
Juliano	Air Crew
Radowsky	Crew Chief
Rowe	Chemist
Mader	Technician
Caldwell	Technician
Merrill	Technician
Pierce	Met. Observer
Allen	Met. Observer
Sheppard	Met. Observer
Swistak	Photographer
Fortenbacker	Ordnance Specialist

From the Natural Sciences Institute of the Atmospheric Science Research Center, State University of New York at Albany:

Schaefer	Field Director
Lala	Asst. Field Director
Eight Students	

From the U. S. Forest Service Forest Fire Laboratory, Missoula, Montana:

Fuquay	Visitor - AgI effects

From National Center for Atmospheric Research, Boulder, Colorado:

Sardor	Visitor - Cloud Physics

Other visitors are expected during the field program but a complete listing at this time is not possible.

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STUDY AND MODIFICATION OF CONVECTIVE STORMS.
P. B. MacCready, Jr., T. B. Smith, T. J. Lockhart
Interim Rept. No. 2 for 1 Apr. 1963 - 30 June 1963. 24 p.
(Rept. No. MRI63 IR-87)
(Contract DA-36-039 SC-89066, Proj. No. 3A99-27-005-06)
(ARPA Order No. 265-62) Unclassified report.

This interim report describes the preparation phase of the second year of a basic research program in cloud physics, cloud dynamics, and related cloud modification. The program scope is defined and includes 1) General Cloud Microphysics and Dynamics Study, 2) Cloud Cell Dynamics and Edge Study, 3) Seeding, 4) Droplet Concentrations, 5) Mountain Wake Effects, 6) Thermal Roots Relative to Mountains, 7) Cloud Area Dynamic Effects, 8) Cloud and Precipitation Development Census, 9) Thunderstorm-Created Cold Front, 10) Electrification, 11) Freezing Nuclei, and 12) Technique Development. Instrumentation, including Radar Systems (M-33 and MR-4), Aircraft Systems (Piper Apache and Cessna 180), Photographic Systems, and Miscellaneous Instruments, is described. Facilities are listed as are suggested research topics for students participating under the guidance of Dr. Vincent Schaefer.

UNCLASSIFIED

1. Clouds-Physical properties.
2. Clouds-Electrical properties.
3. Cumulus clouds-Growth.

I. Title: Project Baton
II. MacCready, P. B., Jr.
III. U.S. Army Electronic R&D Lab., Ft. Monmouth, N.J.
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